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(71) Applicant: Fujii, Hitoshi
818, North 25 West 13
Kita-ku Sapporo-shi Hokkaido(JP)

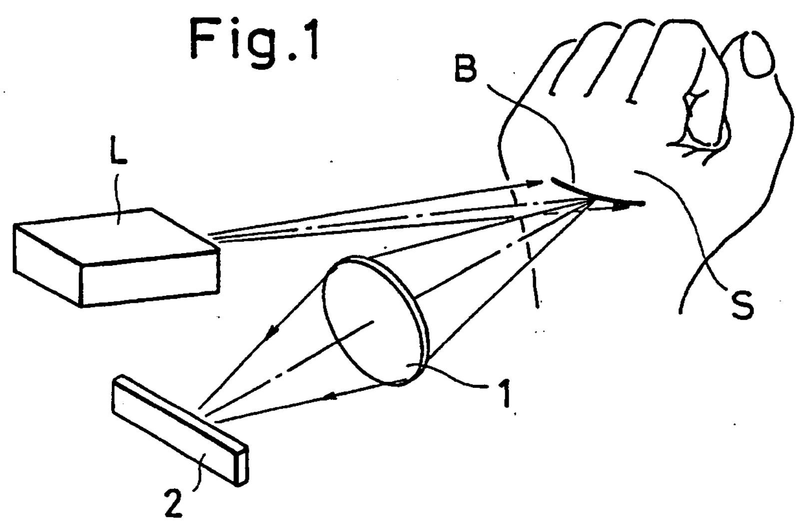
(72) Inventor: Fujii, Hitoshi
818, North 25 West 13
Kita-ku Sapporo-shi Hokkaido(JP)

(74) Representative: Corin, Christopher John et al
Mathisen Macara & Co. The Coach House 6-8
Swakeleys Road
Ickenham Uxbridge UB10 8BZ(GB)

(54) Apparatus for monitoring a bloodstream.

(57) Apparatus for monitoring bloodstream in the skin surface (S) includes a laser light source (L) for projecting a laser beam onto the surface and an objective lens (1) for collecting light reflected from the surface and scattered by blood cells, and focusing it onto a linear image sensor (2). The signals read out of the elements of the linear image sensor are converted into digital signals and stored in a memory (5). A calculating circuit (7) evaluates bloodstream velocity or the velocity distribution from these stored values and a display device (6) shows the calculated values.

Fig.1



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APPARATUS FOR MONITORING A BLOODSTREAM

The present invention relates to an apparatus for monitoring a bloodstream flowing through a blood vessel, and more particularly to an apparatus for measuring a distribution and a variation in time of an average velocity of a bloodstream in a skin surface of a patient by means of the laser speckle method.

When laser light is incident upon a living tissue such as skin, the laser light is scattered by particles constituting the blood, and scattered light rays interfere with each other to form a random pattern, i.e. a speckle pattern. This speckle pattern changes in time due to the movement of the blood cells in the blood vessel. Therefore there can be derived a noise-like signal representing the velocity of the bloodstream by measuring the variation in time of the intensity of light scattered from a certain point on the skin. This phenomenon was found by Dr. M.D. Stern et al around the year 1975. By utilizing this phenomenon, the bloodstream can be measured with the aid of frequency analysis of the speckle signal without damaging the skin. The study of this phenomenon has been rapidly developed and the apparatus for monitoring the bloodstream has been commercially available as the laser Doppler bloodstream meter.

In the known apparatus, the variation in time of the bloodstream at a point is detected with the aid of an optical fibre scope, or any abnormal condition is detected by comparing the measured data with data from a standard reference point. However, in the known laser Doppler bloodstream meter using the optical fibre, since an area of the detection point has a very small diameter such as several millimeters, the measured data fluctuates for respective measuring points. Therefore, the existing apparatus is not suitable to estimate the bloodstream in a rather large area. Further, since the signal obtained via the optical fiber scope is inherently noisy, there must be provided an integrating circuit or low pass filter for smoothing the noisy signal. When the time constant of these circuits is made large, the variation of the bloodstream can be displayed slowly, but the sensitivity to any rapid change in the bloodstream is decreased.

This inability to display the variation in time of the bloodsteam with a high response sensitivity, or to indicate the distribution of the bloodstream activity represents a technical problem.

The present invention provides an apparatus for monitoring a bloodstream comprising light projecting means for projecting a laser light upon an object; and light receiving means for receiving laser light reflected from the object; characterised in that the light receiving means comprises a plurality of light receiving elements, and in that the apparatus further comprises memory means for storing output signals read out of the light receiving elements; calculating means for processing the output signals stored in said memory means to derive information about a bloodstream of the object; and display means for displaying the information about the bloodstream.

The apparatus of the present invention is advantageous relative to the existing laser Doppler bloodstream meter using an optical fibre probe because it can respond more quickly to changes in the bloodstream velocity. A further advantage is that the variation of the bloodstream over a larger skin surface can be measured. In this way the information obtained is more useful for diagnosis.

Two embodiments of the invention whereby the bloodstream velocity variation with time or the bloodstream velocity distribution over a portion of the skin may be monitored, will now be described, by way of example only, with reference to the accompanying diagrammatic drawings, in which:

Figure 1 is a perspective view showing the manner of monitoring the bloodstream in the skin surface with the aid of the apparatus according to the invention;

Figures 2(a) and 2(b) are graphs illustrating the output signal of the bloodstream monitoring apparatus;

Figure 3 is a block diagram depicting the construction of the signal processing unit of the bloodstream monitoring apparatus;

Figures 4(a) and 4(b) are graphs illustrating the output signal of the apparatus; and

Figure 5 is a perspective view showing another embodiment of the bloodstream monitoring apparatus according to the invention.

Figure 1 is a perspective view showing - schematically an embodiment of the bloodstream monitoring apparatus according to the invention. The apparatus comprises a laser light source L for projecting a laser light beam B upon a skin surface S. The laser light source L comprises a laser for emitting a laser beam and a cylindrical lens for converting the laser beam emitted from the laser into a rectilinear beam having a width of several centimeters. The laser light reflected by the skin surface S is incident upon a linear line sensor 2 via an objective lens 1. The linear line sensor 2 comprises a number of light receiving elements arranged in one direction. On the light receiving surface of the line sensor 2 there is formed the speckle pattern which varies in time in accordance with the movement of blood cells in blood vessels within the skin surface S. Therefore, by scanning

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the line sensor 2, there may be obtained photoelectric signals representing the variation in time of the speckle pattern.

Figures 2(a) and 2(b) are graphs showing the variation in time of the output signal from the line sensor 2, while the laser light is incident upon the skin surface S at the same point. Solid line and broken curves represent the output signals at different timings. Figure 2(a) shows the output signals when the bloodstream velocity is high, and the curve shown in Figure 2(b) denotes the output signals when the velocity of the bloodstream is low. In Figure 2(a), the output signal at the second timing is greatly different from that at the first timing due to the large variation of the speckle pattern. On the contrary, the output signals at the first and second timings shown in Figure 2(b) are substantially the same as each other, because the variation of the speckle pattern is small. Therefore, when differences between the output signals from each of the image sensing elements in the sensor 2 at different timings are derived and are accumulated, an accumulated value becomes large for the Figure 2(a) condition and remains relatively small for the Figure 2(b) condition. By effecting the operation at a high speed, it is possible to trace the variation in time of an average velocity of the bloodstream along a given line.

Figure 3 is a block diagram showing a signal processing unit. An output signal from the line sensor 2 is successively supplied to video amplifier 3, A/D converter 4, memory 5 and display 6. These circuits are connected to a microcomputer 7 and are controlled by the microcomputer and signals are transmitted between the circuits and the microcomputer.

The line sensor 2 comprises 256 light receiving elements and output signals successively read out of the elements are amplified by the video amplifier 3 and are converted into digital signals by the high speed A/D converter 4. These digital signals are then stored in the memory 5. Under the control of the program stored in the microcomputer 7, differences between output signals at successive samplings from each of the light receiving elements are calculated and then these differences thus calculated are accumulated. The calculation is carried out in the following manner.

Now it is assumed that the number of light receiving elements of the line sensor 2 is N, and output signals from n^{th} light receiving element an timings t and t + Δt are expressed by I(t,n) and I-(t+ Δt,n), respectively. Then, the accumulation value V(t) can be calculated as follows.

$$V(t) = \sum_{n=1}^{N} \left| I(t,n) - I(t+ t,n) \right|$$

The accumulated value V(t) is proportional to the average velocity of the bloodstream at the timing t. The above calculation is performed at a high speed, and the calculated value is displayed on the display 6 as a series of waveforms or is supplied to a recorder. In this manner, the variation in time of the bloodstream can be measured.

In the embodiment so far explained, the variation of the bloodstream velocity in time is measured. According to the invention, it is also possible to display the distribution of the bloodstream by changing the program stored in the microcomputer 7.

Figure 4(a) shows output signals read out of the line sensor 2 at two successive timings, while the laser beam is incident upon a position of the skin surface. In the right hand half of the graph, the blood stream velicity is high, while in the left hand half, the bloodstream velocity is low. In the right hand half, since the pattern shows the large variation, values of the output signals at respective light receiving elements differ largely from each other, but in the left hand half, the differences are small. Therefore, when these differences are accumulated for respective light receiving elements for a predetermined period, it is possible to obtain the distribution of the bloodstream velocity in the scanning line as shown in Figure 4(b).

The above mentioned scanning is repeated several hundred times and data thus obtained is stored in the memory 5. Then, under the control of the program stored in the microcomputer 7, there are derived differences between the outputs of two successive scannings. This operation may be performed in the following manner.

Now it is assumed that an output signal from n^{th} light receiving element of the line sensor 2 in the k^{th}scanning is denoted by Ik(n) and that in $(k+1)^{th}$scanning is represented by Ik+1(n). Then, an absolute value of a difference between these output signals can be derived as follows.

$$\Delta k(n) = \quad Ik(n) - Ik+1(n)$$

The differences are accumulated for a number of scanning times M.

$$V(n) = \sum_{k=1}^{M} \Delta k(n)$$

Then, V(n) thus calculated is proportional to the bloodstream velocity at a relevant point. The values V(n) are calculated for each of the N light receiving elements to obtain the distribution of the blood-

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stream velocity along the measuring line B on the skin surface S. Then the distribution curve is displayed on the display 6 as illustrated in Figure 4-(b).

When at least one of the skin surface S and the measuring system including the objective lens 1 and line sensor 2 is moved in the direction perpendicular to the direction of the scanning line B, it is possible to obtain a two dimensional bloodstream velocity distribution over a certain area of the skin surface S.

Figure 5 is a perspective view illustrating another embodiment of the bloodstream monitoring apparatus according to the invention. In the present embodiment, the two dimensional distribution of the bloodstream is measured with the aid of the linear line sensor. A laser light beam emitted from a He-Ne laser light source 11 is expanded in one direction by means of a cylindrical lens 12 and is made incident upon the skin surface S via a reflection mirror 14 which is swung by an electric motor 13 at a constant speed. Therefore, the skin surface S is scanned with the laser beam in a direction A shown in Figure 5. The laser beam reflected by the skin surface S is reflected again by the swinging mirror 14 and is then made incident upon a line sensor 16 via an objective lens 15.

By swinging the mirror 14 to move the scanning line B in the direction A, the skin surface S is scanned two-dimensionally and a two-dimensional map of the bloodstream can be formed. Such a map is quite useful for diagnosis. Further, the map may be displayed on a color monitor in such a manner that different velocities of the bloodstream velocity are displayed with different colors. With the aid of such a colored map, it is possible to grasp the condition of the bloodstream in fine blood vessels at a glance. Such a colored map may be effectively used together with a thermography image of the area.

In the above embodiments, the scattered light is detected by the linear line sensor, but it is also possible to detect the scattered light by means of a two-dimensional image sensor. By using a two-dimensional sensor, the variation in time of the bloodstream velocity and the bloodstream distribution may be detected two-dimensionally. In this case, a laser beam expanded in two orthogonal directions has to be made incident upon the object.

Moreover, when the sensitivity of the two-dimensional image sensor, i.e. CCD, or the output power of the laser light source is sufficiently high, the useful data may be obtained without moving the object and measuring system relative to each other by expanding the laser light two-dimensionally.

As explained above, in the bloodstream monitoring apparatus according to the invention, it is possible to display the variation of the bloodstream and the distribution of the bloodstream which are very useful for diagnosis. As compared with the known laser Doppler bloodstream meter using the optical fibre probe, the response for the bloodstream change is very high and the field of detection can be made wider.

Claims

1. An apparatus for monitoring a bloodstream comprising light projecting means (L; 11, 12, 14) for projecting a laser light upon an object (S); and light receiving means (1, 2; 14, 15, 16) for receiving laser light reflected from the object (S); characterised in that the light receiving means (2; 16) comprises a plurality of light receiving elements, and in that the apparatus further comprises memory means (5) for storing output signals read out of the light receiving elements (2; 16); calculating means (7) for processing the output signals stored in said memory means to derive information about a bloodstream of the object (5); and display means (6) for displaying the information about the bloodstream.

2. Apparatus according to claim 1, characterised in that said laser light projecting means comprises a laser light source (L; 11) for emitting a laser beam, and an optical element (12) for expanding the laser beam in one direction.

3. Apparatus according to claim 2, characterised in that said laser light source comprises a He-Ne laser.

4. Apparatus according to claim 2, 3 or 4, characterised in that said optical element comprises a cylindrical lens (12).

5. Apparatus according to claim 3 or 4, characterised in that said light receiving means comprises an objective lens (1, 15) for collecting light rays reflected from the object (S), and having a number of said light receiving elements arranged in a line image sensor (2; 16) extending in said one direction in which the laser beam is expanded.

6. Apparatus according to claim 5, characterised in that said laser light projecting means further comprises a mirror (14) arranged rotatably about an axis which extends in said one direction, and an electric motor (13) for rotating the mirror (14), whereby said objective lens (15) is arranged between the mirror (14) and the line image sensor (16).

7. Apparatus according to claim 1, characterised in that said laser light projecting means comprises a laser light source for emitting a laser beam, and an optical element for expanding the

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laser beam in two orthogonal directions, and in that said light receiving means comprises a two dimensional image sensor.

8. Apparatus according to any one of the preceding claims, wherein said calculating means (7) calculates an average velocity of the bloodstream.

9. Apparatus according to claim 8, characterised in that said calculating means performs the following calculation;

$$V(t)=\sum_{n=1}^{N}\left|I(t,n)-I(t+\Delta t,n)\right|$$

wherein N is the number of the light receiving elements, I(t,n) is an output of n^{th} light receiving element at a sampling time t, and $I(t+\Delta t,n)$ is an output of n^{th} light receiving element at a next sampling time $t+\Delta t$.

10. Apparatus according to any one of the preceding claims, characterised in that said calculating means calculates a distribution of the bloodstream.

11. Apparatus according to claim 10, characterised in that said calculating means performs the following calculation;

$$V(n)=\sum_{k=1}^{M}\Delta k(n),$$

wherein $\Delta k(n) =$ $Ik(n)-Ik+1(n)$, Ik(n) and Ik+1(n) are outputs of n^{th} light receiving element at k^{th} and $(k+1)^{th}$ samplings, respectively, and M is the number of samplings.

12. Apparatus according to claim 10 or 11, characterised in that said display means (6) comprises a color monitor for displaying different levels of said distribution of the bloodstream as different colors.

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Fig.1

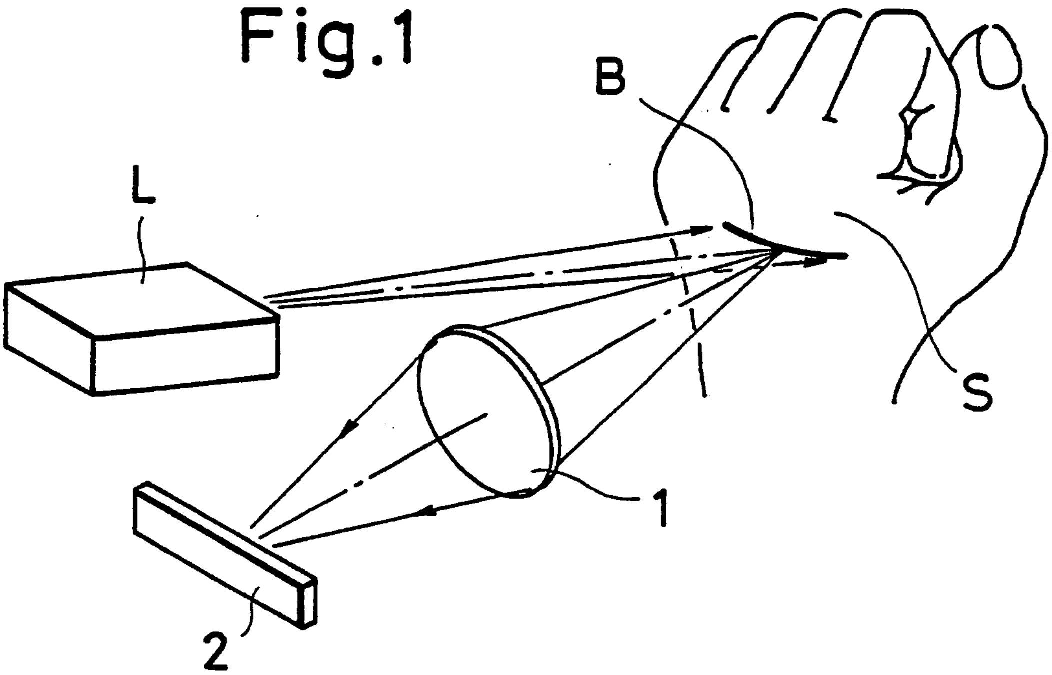

Fig.2(a)

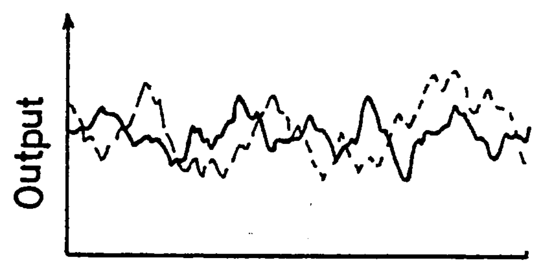

Fig.2(b)

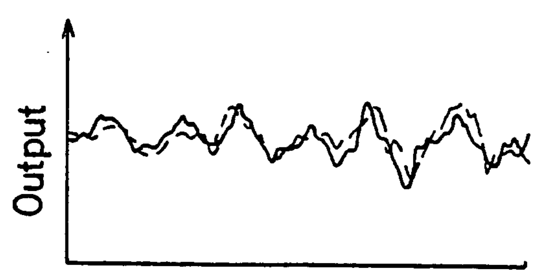

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Fig.3

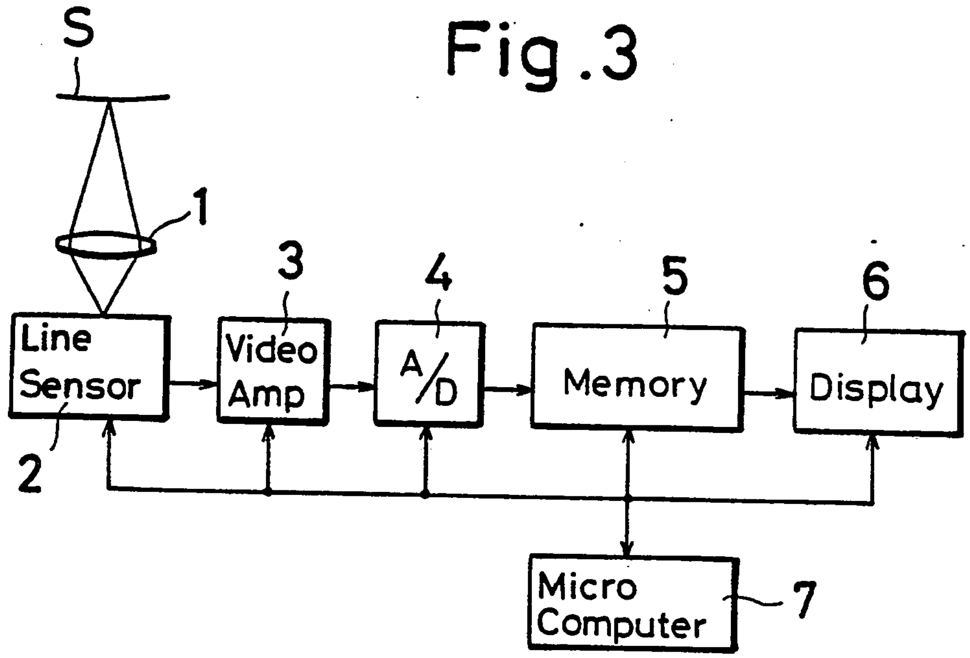

Fig.4(a)

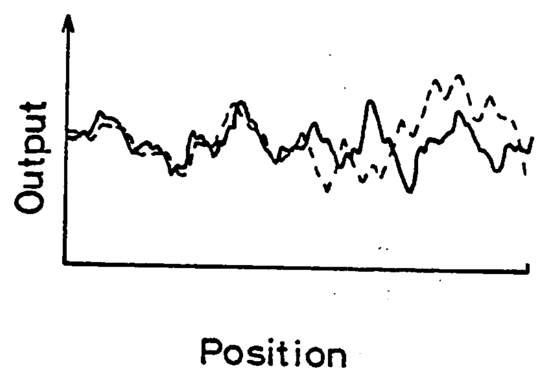

Fig.4(b)

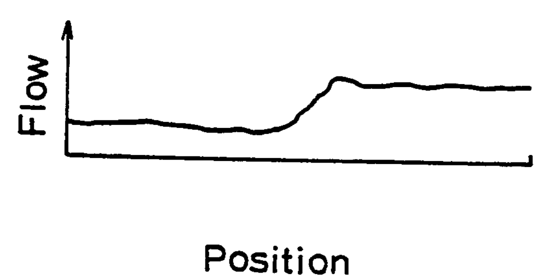

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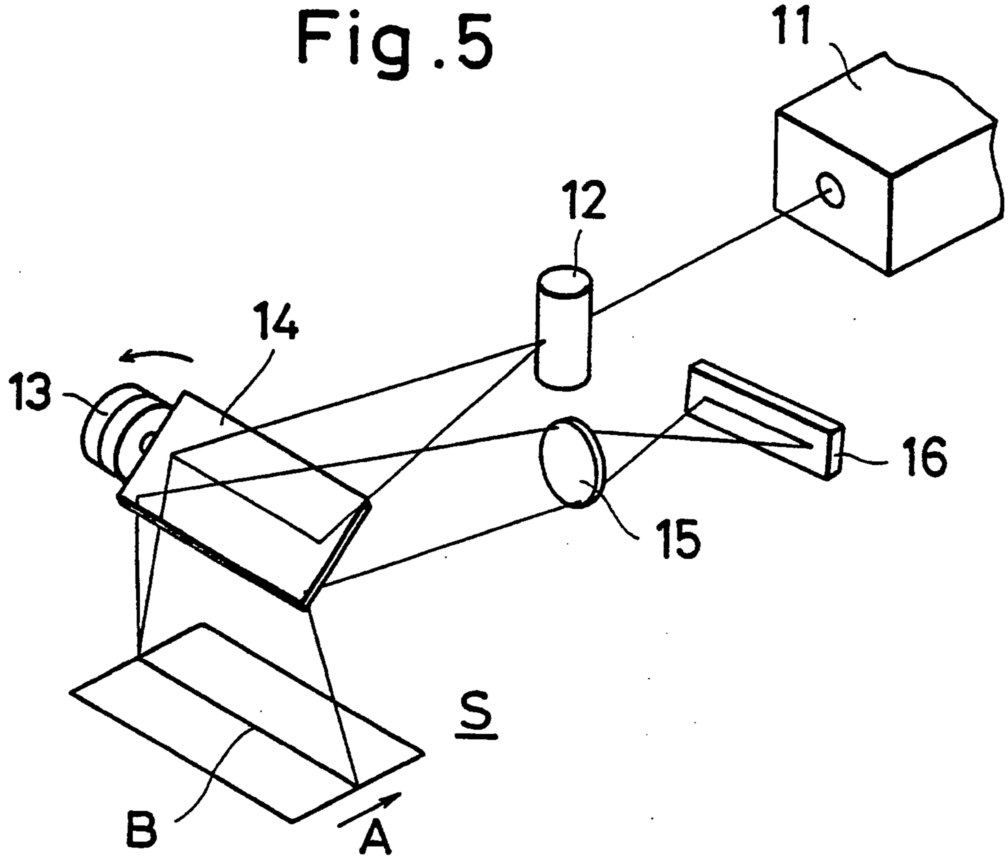
Fig.5



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EUROPEAN SEARCH REPORT

Application Number

EP 88 30 1716

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	FR-A-2 537 428 (C. ZEISS) * Abstract; page 5, line 13 - page 10, line 9; page 16, lines 5-36; figures 1-7 * ---	1-3,6,7,10,12	A 61 B 5/02
A	FR-A-2 561 515 (R. AMAR) * Abstract; page 1, lines 1-24; page 2, lines 4-14; page 3; claims 1,4; figure * ---	1,5,12	
A	IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, vol. BME-32, no. 6, June 1985, pages 439-447, IEEE, New York, US; L. DUTEIL et al.: "A double wavelength laser doppler system to investigate skin microcirculation" * Pages 439-440, "Abstract", paragraphs IIA: "Optical Part" and 2B: "Lasers"; figures 1,2 * -----	1,3	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			A 61 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	14-06-1988	RIEB K.D.

CATEGORY OF CITED DOCUMENTS

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